# Materials Science with Ultra-Bright, Ultra-Fast X-Ray Sources

## Scientific Achievement

Working with the SPPS collaboration, we have made significant progress on several of the most important challenges facing users of the new, extremely high peak brightness x-ray sources being constructed by the Department of Energy. First, in work lead by Adrian Cavaleri, we have demonstrated that synchronization can be achieved between a pump laser and an x-ray pulse to better than 100 fs. (Phys. Rev. Lett., **94**, 114801(2005)). In work lead by Aaron Lindenberg, we have followed atomic displacements during laser melting of surfaces with sub-100 fs resolution (Science, **308**, 392(2005)). This work has been extended into a longer time regime in work lead by Kelly Gaffney (Phys. Rev. Lett., **95**, 125701(2005)). Unlike a conventional (DC) or storage ring (millions of pulses/second) where only one photon is counted at a time, SPPS and eventually LCLS will produce large numbers of photons/pulse. We have developed techniques to monitor the intensity and to accurately measure data using the very low repetition rate of the SPPS.

## Significance

The continued development of synchrotron sources with brighter x-ray beams and shorter x-ray pulses leads to impressive new capabilities and scientific opportunities. Not surprisingly, there are also significant challenges associated with using such radically new capabilities. This work seeks to integrate the impressive new capabilities of synchrotron sources with novel instrumentation, and to use those instruments to characterize new materials and materials processing. This goal requires the development of 1) the ability to manipulate single nanoparticles with very low backgrounds and with the capability to rapidly introduce new particles, 2) x-ray detection systems that can bin photons of different energy in a sub-100 fs pulse and accurately count the number of photons in each bin, and 3) time synchronization technologies which can determine the time difference between the x-ray pulse and a femtosecond laser on a pulse by pulse basis. The work described here has innovative solutions to each of these challenges.

## Performers

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The SPPS Collaboration, in particular Adrian Cavaleri (U. of Mich.) and Aaron Lindenberg (SSRL-SLAC)

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Average Spectral Brightness (Photons/s-mm$^2$-mr$^2$-0.1% bandwidth)

$10^{10}$ $10^{12}$ $10^{14}$ $10^{16}$ $10^{18}$ $10^{20}$ $10^{22}$

Tube APS LCLS

**Lightbulb**
**X-ray Tube**

**Searchlight**
**Advanced Photon Source**
$\sigma_t$ = 100 ps

**Laser**
**LCLS**
$\sigma_t$ = 1-200 fs

Tube APS LCLS

$10^{10}$ $10^{14}$ $10^{18}$ $10^{22}$ $10^{26}$ $10^{30}$ $10^{34}$

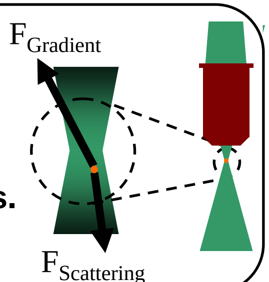
Peak Spectral Brightness (Photons/s-mm$^2$-mr$^2$-0.1% bandwidth)

**Unprecedented characterization capabilities to Improve Materials and Processing are enabled by these exceptional x-ray sources.**

## Single Nanoparticles

**Goal: Perform x-ray scattering measurements from single nanoparticles.**

**Use laser traps to hold individual nanoparticles.**

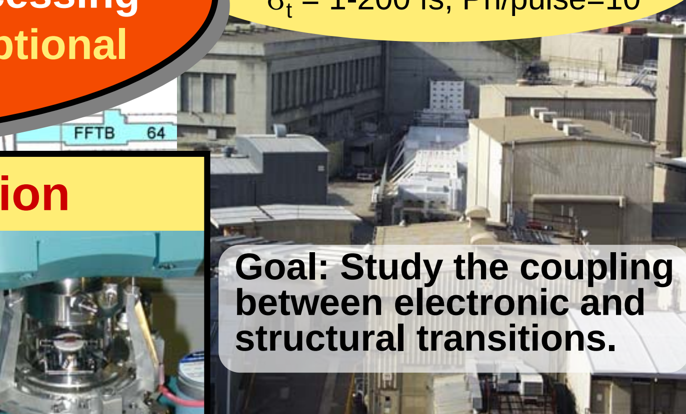



## *In Situ* Characterization

**Goal: Follow the structural and chemical evolution of materials *in situ*; improve and control materials synthesis.**

## Femtosecond Dynamics

**Sub-Picosecond Photon Source**
$\sigma_t$ = 1-200 fs, Ph/pulse=$10^8$




**Goal: Study the coupling between electronic and structural transitions.**


Paul Fuoss and
G. Brian Stephenson

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